NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

AFCRL 865

EVALUATION OF A PRESSURE DETECTOR AS A DEEP WELL SEISMOMETER

By
Robert A. Broding
Daniel P. Hearn

CENTURY GEOPHYSICAL CORPORATION
515 South Main
Tulsa, Oklahoma

Report No. P-4-61-2

Contract No. AF 19(604)-8454

August 23, 1961

61-4-5

Prepared
for

GEOPHYSICS RESEARCH DIRECTORATE
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

WORK SPONSORED BY ADVANCED RESEARCH PROJECTS AGENCY

PROJECT VELA UNIFORM

ARPA Order No. 180-61, Amendment 2
Project Code No. 8100, Task 2

CENTURY

EVALUATION OF A PRESSURE DETECTOR AS A DEEP WELL SEISMOMETER

I N D E X

ILLUSTRATIONS

Figure

REPORT
ON
EVALUATION OF A PRESSURE DETECTOR AS A DEEP WELL SEISMOMETER

Contract Number: AF19(604)-8454

I. OBJECT

The object of this study is to evaluate the use of a pressure sensor as a seismic detector for deep hole detection of underground nuclear explosions.

II. GENERAL

In the procedures for detection of travel time from surface shots to a bore hole detector in oil well velocity surveying, pressure detectors have proven to be superior to inertial detectors. The pressure detectors commonly used employ a diaphragm operated reluctance sensor so the signal output is proportional to the rate of change of pressure. Recent experiments with ceramic sensors of the lead zirconate titanate type have shown sensitivities equal to or greater than the best reluctance type pressure sensor at frequencies in the order of 100 c.p.s. or more. The use of these new ceramic sensors makes it possible to have a flat pressure vs. frequency response down to 1 c.p.s. Figure 1 illustrates the response of a ceramic and reluctance type pressure detector at a depth of 10,000 feet to a surface charge of only 2-1/2 pounds.

Therefore, at low frequencies the ceramic elements should have a much greater output than the reluctance type pressure detectors. The complete well seismometer is shown in Figure 2.

This study covers the modification of a deep hole pressure detector of the lead zirconate titanate type for response down to 1 c.p.s. and the measurement of noise in the bore hole compared to a surface Benioff seismometer as well as a bore hole inertial detector.

III. SUMMARY OF RESULTS

1. The goal of a pressure resolution of .02 dynes/cm^2 was not realized. A noise level equivalent of .113 dynes limited the usable sensitivity. This was the result of a higher peak to peak noise level than originally estimated, in combination with a slightly lower transducer output than calculated.

2. In-hole measurements of background noise were well above the limiting input resistor noise for all tests. There is some question as to whether or not the noise is self-generated in the transducer with pressure applied or is actual hole noise. The concept of relaxing of domains of stress with pressure in the ceramic has been suggested by transducer manufacturers and may produce this noise.

3. It was necessary to clamp off the supporting cable and to pressure seal the casing head to reduce surface noise and ambient pressure fluctuations.
4. There was no major change in noise level with depth.
5. Comparison background measurements between a short period surface Benioff and the bore hole detector gave no evidence of correlation.
6. Comparison background measurements between a 1 c.p.s. inertial responsive detector in a nearby bore hole at the same depth gave only poor evidence of correlation on strong signals.
7. Recording of shot events indicates a superiority of wall clamped inertial transducers. This undoubtedly is a result of a better coupling coefficient tied into using a velocity responsive system with a relatively high frequency pulse.
8. The results of these tests are not conclusive. They strongly suggest use of a pressure detector in which the sensor is not a ceramic to qualify whether or not the in-hole noise is seismic or self-generated noise.

IV. INSTRUMENTATION

A. Transducer Element

The ceramic element used measures 4 inches long and 3 inches in diameter with a 1/4-inch wall thickness.

The simplified mounting used is shown in Figure 3. This is the mounting as used in the tests of Figure 1 and has been successfully used to depths in the order of 18,000 feet. Tests were made with both fluid and air backing of the element. Air backing presents a structural design problem for deep hole surveys but results in a greater output per unit pressure change.

B. Computed Sensitivity

The open circuit voltage output per unit hydrostatic pressure for a radial polarized tube with exposed ends was calculated in accordance with the derivation by Langivin[1]:

$$\frac{V}{P_o} = b[\ gp(1 - \frac{\rho}{T} + \rho) + g_t(2 - \rho)]$$

Where: V = Open circuit voltage

P_o = Pressure in newtons/meter^2
(Let P_o = 1 dyne/cm^2 = 0.1 newton/m^2)

b = Outer radius in meters or .038 meters

gp = 20×10^{-3} volt/meter//newton/meter^2

gt = -10×10^{-3} volt/meter//newton/meter^2

ρ = Inner to outer radius ratio or .824

[1] Langivin, R. A., "The Electro-Acoustic Sensitivity of Cylindrical Ceramic Tubes", Journal of the Acoustical Society of America, Vol. 26, No. 3, pp 421-427, May 1954.

For the above ceramic element the open circuit voltage is calculated at 37.4×10^{-6} volt/dyne/cm^2.

C. Bore Hole Amplifier

To make use of the above calculated voltage a high input impedance amplifier with low inherent noise is necessary. Initially an amplifier using an electrometer tube input and a transistor amplifier proved to have a noise level above the input resistor noise, and therefore an all vacuum tube type amplifier was built and is diagrammatically illustrated in Figure 4. A 60-cycle rejection filter was included in the amplifier as it was found very difficult to measure noise levels in the laboratory due to AC pickup at such impedances and voltage levels. The electrical response of the preamplifier is shown in Figure 5.

D. Surface Amplifier

The signals from the bore hole preamplifier were transmitted over a cable pair to a special high gain, low noise amplifier including filtering and suitable for driving a recording oscillograph. This amplifier is shown schematically in Figure 6. The only transformer in the system is the special input transformer. The over-all electrical response at the different filter positions is shown in Figure 7. The input noise level

referred to the first stage grid is in the order of 2 microvolts. Since the over-all gain of the preamplifier, including the logging cable, is 30, signals from the preamplifier will override any noise level in the surface amplifier system.

E. Recording

All recording was made on a modified Century 452 oscillograph for silver emulsion papers and a Century 444 Ultragraph for direct writing oscillographs. The normal chart speed was 12 inches/minute with one second time marks.

V. SYSTEM CALIBRATION

A. Pressure Calibration

A measure of the absolute pressure sensitivity of the seismometer was made by means of a setup as shown in Figure 8. A small reciprocating piston with a variable speed drive was used to provide a near sinusodial pressure pulse to the transducer via water jacket surrounding the transducer. As the piston moved it displaced air in the cylinder which in turn pressured the water column. A 0.1 inch change in water level was used throughout the calibration tests. This is equivalent to a pressure change of 250 dynes/cm^2. A pressure change of this

magnitude produced a signal well above the normal atmospheric pressure change and room noise level. Pump speed in the range of 1 - 4 c.p.s. was used in calibration.

The calibration included the complete instrumentation system to allow an accurate in-hole pressure determination. Therefore, the logging cable was included in the setup. Because of the large signals obtained from this pressure pulse, an attenuation box was inserted before the surface amplifier. Oscillator tests were made to determine the dynamic range of the preamplifier to be certain that this pressure pulse did not overload the preamplifier. A signal level of 10 millivolts at the input of the preamplifier gave no visible distortion. This is well above the calibration signal level. A typical oscillogram recording of the pump calibration is shown in Figure 9. The attenuator box setting inserted 40 db loss to the amplifier equivalent to that obtained from 2.5 dynes/cm^2 if the attenuator were not present. The trace recording indicated a peak to peak deflection of 1.8 inches at 2 c.p.s. Therefore, the peak to peak deflection sensitivity is:

$$1.8 \text{ inches}/2.5 \text{ dynes/cm}^2 = 0.72 \text{ inches/dyne/cm}^2.$$

(See Figure 9.)

A complete frequency response could not be run because of pump limitations, but through the range of 1 - 4 c.p.s. the response followed the electrical system response closely.

B. Electrical Calibration

A signal was injected to the input of the preamplifier in place of the transducer. Under an attenuator setting of 10 db and identical system gain, a 10 microvolt RMS signal gave a trace deflection of .93 inches peak to peak. Converting the input signal to peak to peak volts*, or 28 microvolts, gave a sensitivity equivalent of

$$28\ \mu V/.93(3) = 10\ \mu V/''.$$

Therefore, the peak to peak system sensitivity is equal to 10 microvolts/inch of trace movement. On the basis of trace deflection of 0.72 inches/dyne/cm^2 and 10 μV/ inch for a fluid backed transducer, the output is

$$1\ \text{dyne/cm}^2 = 0.72(10) = 7.2\ \mu V \text{ peak to peak.}$$

Similar tests made with an air backed transducer gave an output of 32 μV/dyne/cm^2. This value checks well with the computed sensitivity.

It is now of interest to determine the instrumental noise level as it will limit the pressure resolution.

---

* Conversion from RMS to peak to peak values is on the basis of a sine wave approximation where the factor is 2.8 times the RMS value. This obviously is not true for transient wave forms but is a fair approximation for these tests.

C. Noise Level

The transducer was suspended in the test stand identical to the pressure tests except that the pump system was not operated. It was necessary to turn off all circulating fans and be certain that no doors in the building were opened. With building activity as quiet as possible, a peak to peak trace deflection as low as 0.12 inches was recorded with an attenuator setting of 10 db. This is equivalent to 0.36 inches with no attenuation. Using a voltage sensitivity of 10 microvolts/inch as previously measured, gives

$$\text{Peak to peak noise} = .36(10) = 3.6\ \mu V$$

On the basis of a pressure sensitivity of 32 $\mu V/dyne/cm^2$ the noise is equivalent to

$$\text{Noise level pressure evuivalence} = \frac{3.6}{32} = .113\ dyne/cm^2$$

To be certain that this level is thermal noise limited rather than unshielded pressure fluctuations producing a signal on the transducer, the thermal noise was calculated and measured.

D. Thermal Noise Calculation

Noise generated by thermal agitation in the input grid resistor can be estimated from the relation:

$$E^2 = 4\,K\,T\,R\,(f_2 - f_1)$$

Where:

E = RMS voltage

K = Boltzmann's constant = $1.374 \times 10^{-23}\ \frac{\text{joules}}{°K}$

T = Absolute temperature, °K

R = Input resistor

$f_2 - f_1$ = Frequency range.

For a frequency range of 1 - 10 c.p.s at 300 °K and an input resistor of 20 megohms, a voltage of 1.72 microvolts RMS, or 4.8 microvolts peak to peak, is calculated. By reducing the band width to 1 - 4 c.p.s., the RMS noise would be reduced to 1.6 microvolts peak to peak. The noise equivalence was measured by removing the transducer but leaving the grid resistor in place. A voltage of 6 microvolts peak to peak was recorded for a band width of 1 - 4 c.p.s. Thus the system noise level was in the order of that calculated for the input resistor. (See Figure 10.) Further, the value of the grid resistor was lowered and the noise level lowered by the square root of the value of the resistor, which again verified that the noise level is limited by the input resistor.

VI. BENIOFF REFERENCE

For a reference or comparative signal, a 1 c.p.s. Benioff seismometer Type 4681 was mounted on a concrete table firmly embedded in the earth -- approximately 50 feet from the well casing head for the laboratory well tests and on a concrete platform for the Dowell well tests. At the laboratory a drum photographic recorder was used at a chart speed of 60 mm/minute and a 24-hour lead screw. A 4.5 c.p.s. galvanometer was used in conjunction with a resistance box for damping and attenuation control. The system sensitivity was found by the relation

$$M = 95 \frac{X_1}{W_t}$$

Where:

M = Magnification at 1. c.p.s.

X_1 = Trace deflection in mm

W_t = Grams of test weight.

Typical operation sensitivity was at a magnification of 12,030 times. Therefore, one millimeter of trace deflection is equivalent to 83 millimicrons of movement. At this relatively low magnification the noise level gave a good background deflection. A typical recording made during this period is shown in Figure 11. Because of the relatively high frequency galvanometer, high frequency noise was limiting the magnification. The over-all response was very similar to that recorded on

the subsurface detector. After much analysis of the noisy sections of the record, it was found that this noise was the result of a compressor motor in a nearby building. The recording of a quarry blast some 3 miles from the laboratory is included. Because of the compressed time scale these seismograms were considered to be useful only in qualifying seismic activity during the test periods. Therefore, a separate recording was made of the Benioff on a dual channel oscillograph at chart speeds in the order of 3 seconds/inch. This allowed good resolution of wave forms to 10 c.p.s. and a direct comparison between the surface and subsurface signals. However, the recording galvanometers in the dual channel oscillograph had a natural frequency of 30 c.p.s. Therefore, the Benioff exhibited a much higher frequency response than the subsurface detector which was always used with a filter cutoff of 4 c.p.s. Further, the Benioff is velocity sensitive while the well detector is pressure sensitive. This results in better high frequency response for the Benioff.

VII. WELL MEASUREMENTS

A. Laboratory Test Well

Initial measurements were made in a 1320-foot deep laboratory test well. The noise level in the well was

very high, i.e., in the order of 200 $dynes/cm^2$ pressure equivalent. This noise was traced to motion of the well detector as a result of movement of the logging cable. By clamping off the cable at the well head with the casing supporting the cable and with slack in the cable above the clamp, the noise level was reduced to approximately 84 $dynes/cm^2$ pressure equivalent. Thus clamping the cable significantly reduced the noise level, but still the background noise was much too high. Therefore, a run was made in the well with the transducer disconnected but with the complete system operating. A noise level equivalent to 0.5 $dyne/cm^2$ was measured at all levels. Thus the hole noise with the transducer on is real and the input resistor noise level is not limiting the pressure resolution. The in-hole noise measurements checked the in-laboratory measurements, indicating no increase in noise with the cable in the hole.

Tests over extended period of time showed considerable quieting with the seismometer at a given position. It also was found that atmospheric pressure changes were being reflected through the liquid column to the detector. By capping the casing head this noise was greatly reduced. At this point wind noise from derrick movement

appeared to be controlling. Under the quietest conditions a noise level of 2 dynes/cm^2 pressure equivalent was measured. At this sensitivity any surface activity near the well head was easily detected with the seismometer at 1320 feet deep. It is believed that this was the result of the seismic energy traveling via earth conduction to the casing head then via the cable clamp to the cable and ultimately along the cable to the seismometer. In these tests there was no correlation between the random noise of the surface Benioff and the subsurface detector. Large signals, such as dropping a weight or jumping on the ground, were easily detected simultaneously on both systems. Since the travel paths and distance from the seismic source were quite different, these recordings, as expected, were different. Therefore, attempts were made to record several quarry blasts. Within the time limit of the program, good comparison records were not obtained. A typical recording is shown in Figure 12. In this case excessive gain on the well seismometer recorded too great a background deflection as well as the blast signal that saturated the recording amplifier.

B. Dowell Test Well

Measurements were made in the Dowell test well located within the city and in an area of high seismic noise. Again it was found necessary to clamp off the cable and to pressure cap the well casing to minimize cable and atmospheric pressure noise. Figure 13 illustrates this effect. The Benioff seismometer was placed near the well site and comparison records were made on a multichannel oscillograph. Again there was no evidence of correlation between the background noise of the two systems. The hole noise level vs. depth was checked to 3200 feet. (See Figure 14). Tests were made between day and night periods. The high noise level and lack of correlation led to the conclusion that noise checks must be considered with detectors under near identical environments if any degree of correlation can be expected.

C. Jersey Test Wells

Tests were then conducted in cooperation with the Jersey laboratories using test wells and their bore hole inertial detector. Before each operation period the pressure sensitivity of the well detector was checked. Provisions were incorporated by a down-hole switching scheme to 1) turn the subsurface amplifier off, 2) disconnect the transducer with the amplifier on and

terminated only in a grid resistor, and 3) have the amplifier on with the ceramic element connected. These checks verified instrument noise levels compared to in-hole noise levels. The normal grid resistor noise was equivalent to 0.6 dynes/cm^2 while background noise levels were in the order of 3 dynes/cm^2. A typical in-hole calibration check is shown in Figure 16.

Noise checks were then made at levels of 250 to 2000 feet, with the pressure detector in a cased hole and the Jersey wall clamping inertial detector in an uncased hole. Sample oscillograms are shown in Figure 17. There seems to be little to no correlation of events between the two measuring systems. The electrical system response was similar, but the Jersey detector is velocity sensitive while the Century detector is pressure sensitive. Considerable lengths of recordings were made in an attempt to obtain correlation of events, but without success.

Comparison records obtained of signals, including train noise, gave some indication of events that could be correlated but, again, the coincidence was very poor. (See Figure 18.)

Next, seismic pulses were made by dropping weights. Clearly defined pulses were obtained on the pressure detector. The character of these pulses was suspicious

of strong tube waves which were believed to be generated as a result of conduction to the water column by the casing. Figure 19 illustrates weight drop pulses.

Seismic pulses were then generated by shooting small chemical explosives at a distance of 6000 feet from the detection point. These pulses were clearly distinguished on the inertial detectors but were masked by a background build-up coincident with the arrival of the pulse. Surface inertial detection of these pulses was poor compared to the in-hole recording. Reverse positioning of the detectors, i.e., the pressure detector in the open hole and the inertial in the cased hole, indicated a noise build-up again at the energy arrival combined with less background in the uncased hole. The inertial element failed to operate in this test, so comparison was not complete.

VIII. RESULTS

Reliable absolute pressure sensitivity calibrations were possible by the air piston water jacket technique. Prior to this method, and in using higher frequency detectors, we had no means for obtaining an absolute pressure sensitivity check. Therefore, estimates of performance of our higher frequency well seismometers as used in velocity shooting were based only on calculation.

The combination of a higher than calculated resistor noise level tied to a slightly lower than calculated pressure voltage sensitivity limited the laboratory measurements to .113 dynes/cm^2. In the bore hole the noise level was limited to approximately 0.5 dynes/cm^2. A cause of this noise level difference was found to be microphonics in the subsurface preamplifier. By insulating the well detector from mechanical contact with the casing, this difference in noise levels was materially reduced. Insulation was provided by covering the well detector with rubber bumpers to keep the transducer case from contacting the casing.

In all measurements the transducer noise level in the bore hole was well above the limiting grid resistor noise. Therefore, it was assumed that the measured noise was real. However, since correlation records were so poor, other possible noise sources were considered. The most likely source of a self-generated noise outside of the grid resistor is suggested by the phenomenon of relaxing of domains of stress in the ceramic with pressure. No verification of this phenomenon has been possible to date.

Because of the relatively high sensitivity of the system, clamping of the supporting logging cable to the casing head and pressure sealing of the casing head were

important to the quieting of the well phone.

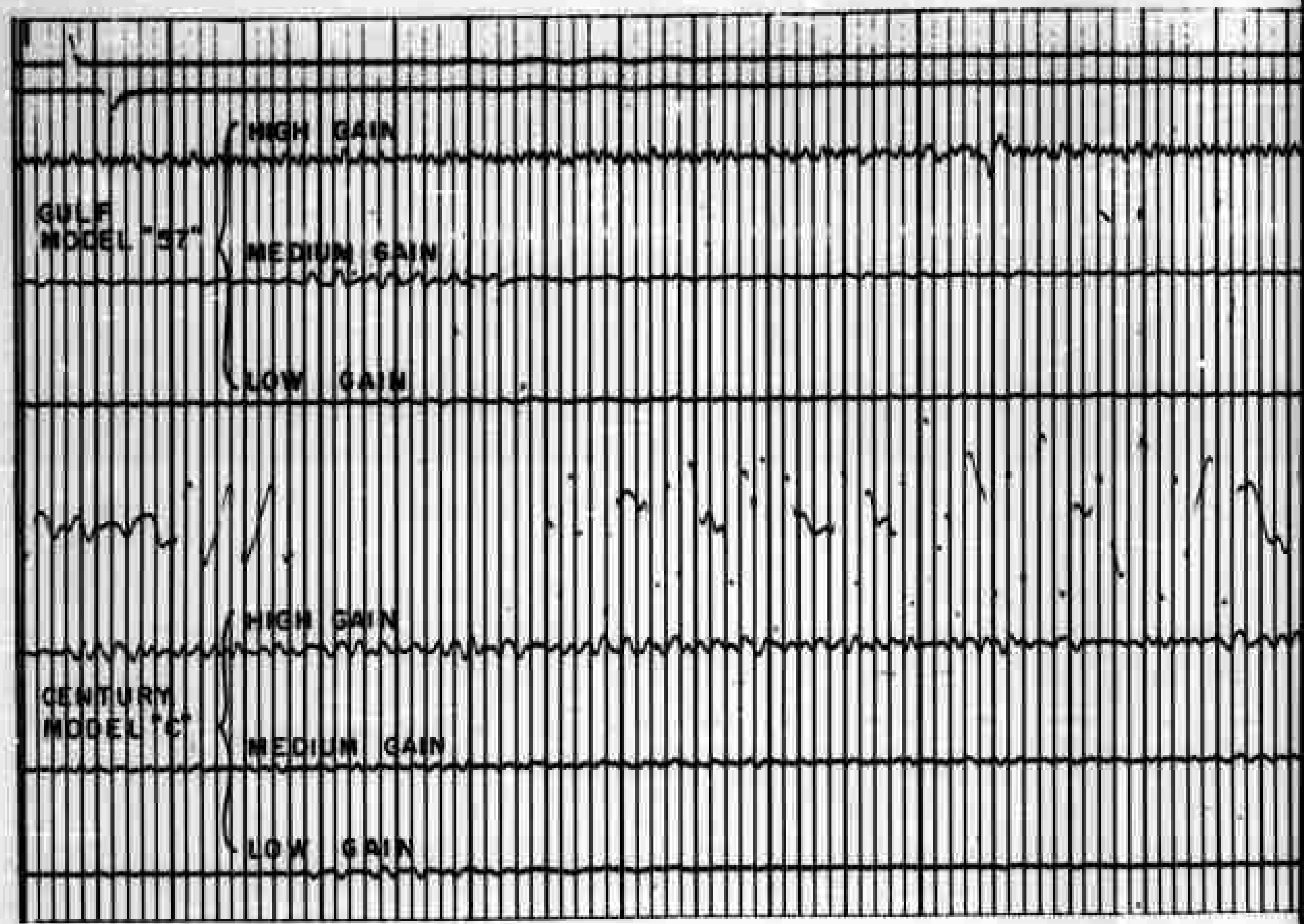
The results of tests in the three sets of well measurements failed to indicate a major change in noise level with depth to approximately 3000 feet. This might suggest the noise being measured was not the earth noise background. However, we have no evidence to date of other noise sources and, therefore, it must be assumed to be earth-generated noise.

Comparison records with a surface Benioff detector failed to correlate hole background noise. It was reasoned that such a comparison was not likely due to the comparison of the surface waves with in-hole noise. Further, difference in response of the two systems would make a direct correlation difficult.

Comparisons using an in-hole seismometer at the same depth also failed to correlate background noise. There was some evidence of primary noise frequencies in the order of 2 c.p.s. Frequencies in this range could be generated by the so-called "organ pipe" effect or tube waves. There also was evidence of such waves associated with weight drop and explosion seismic pulses. A further study of this mode and its elimination is suggested. Since the tube wave phenomenon has not been predominant in conventional well shooting measurements,

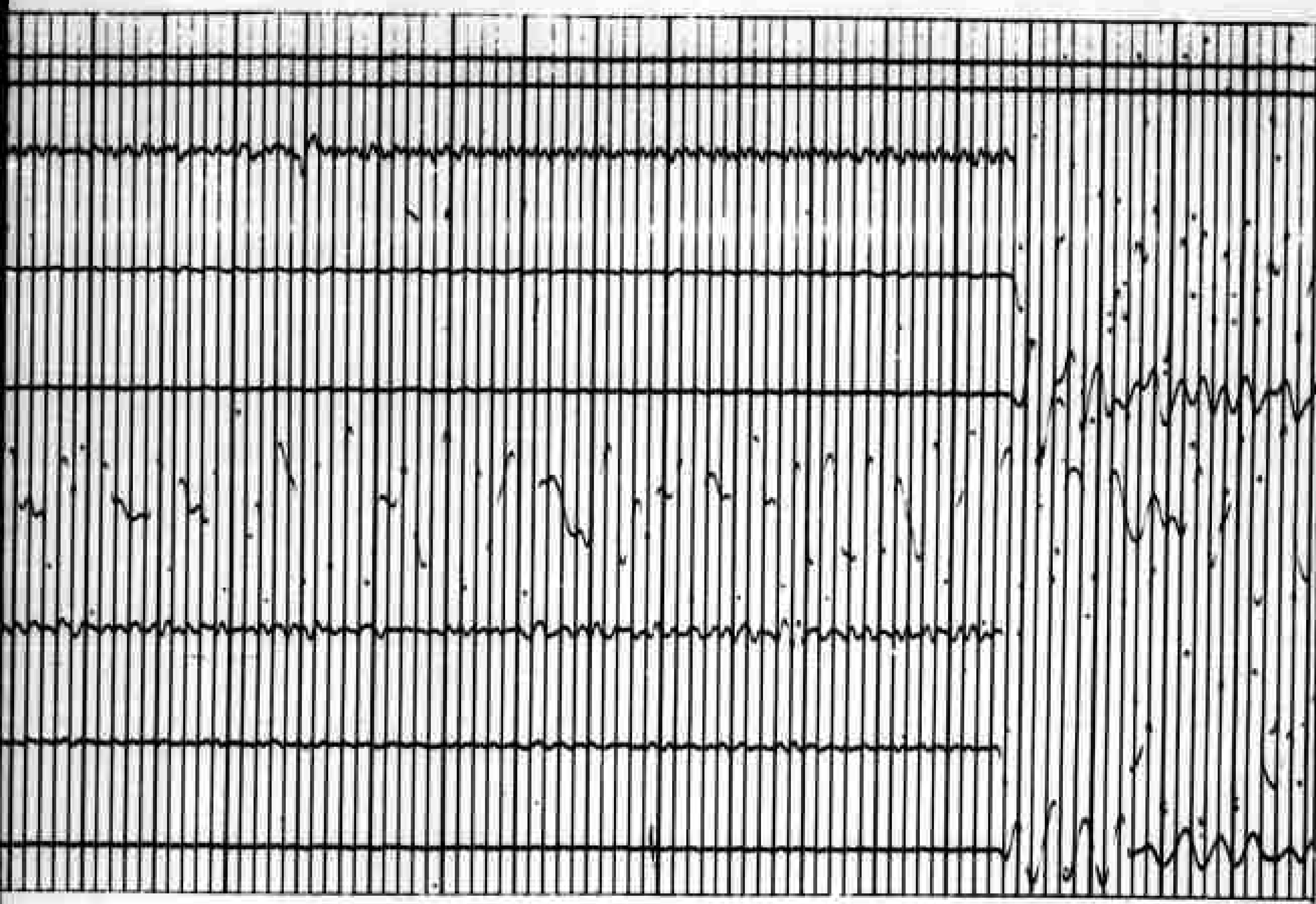
it can only be rationalized that the low frequency cutoff (20 c.p.s.) of well shooting recording systems does not allow long period tube waves to interfere. This also suggests that a solution could be reached by using acoustic plugs in the bore hole, at short intervals, so the tube wave resonance is high or outside the seismic spectrum.

The results of the field tests using small explosions for seismic pulses are not held in complete confidence as, in contrast to our experience with well shooting, the pressure detector should have excelled in performance. Time limitation in use of test holes prevented further confirmation of the results measured. The superiority of a clamped inertial detector in these tests needs further verification before it can be conclusively stated.



COMPARISON OF MODIFIED MODEL "C" PRESSURE DETECTO
WITH STANDARD WELL PRESSURE SE

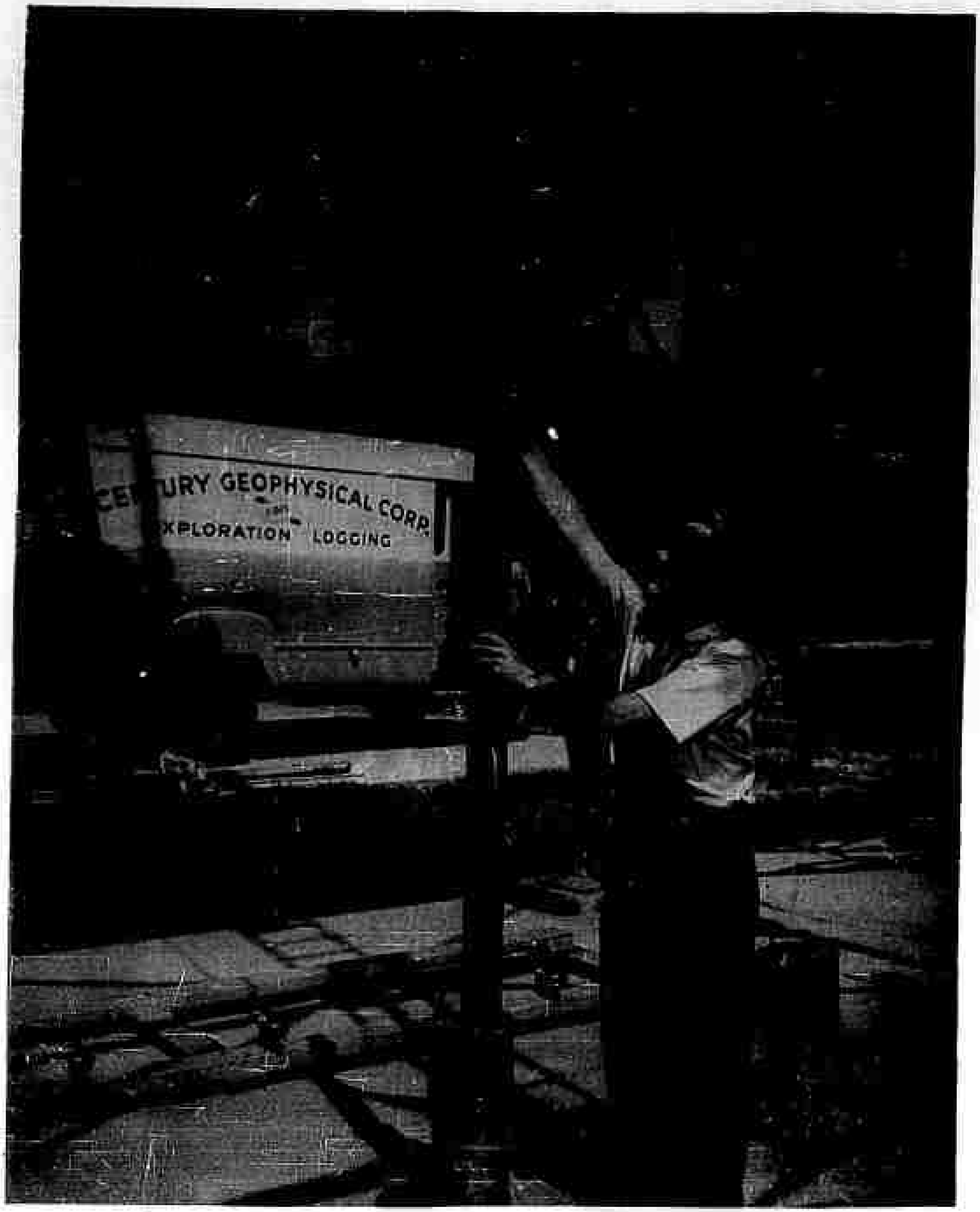
1



ED MODEL"C" PRESSURE DETECTOR FOR 1 C.P.S. RESPONSE
ANDARD WELL PRESSURE SEISMOMETER

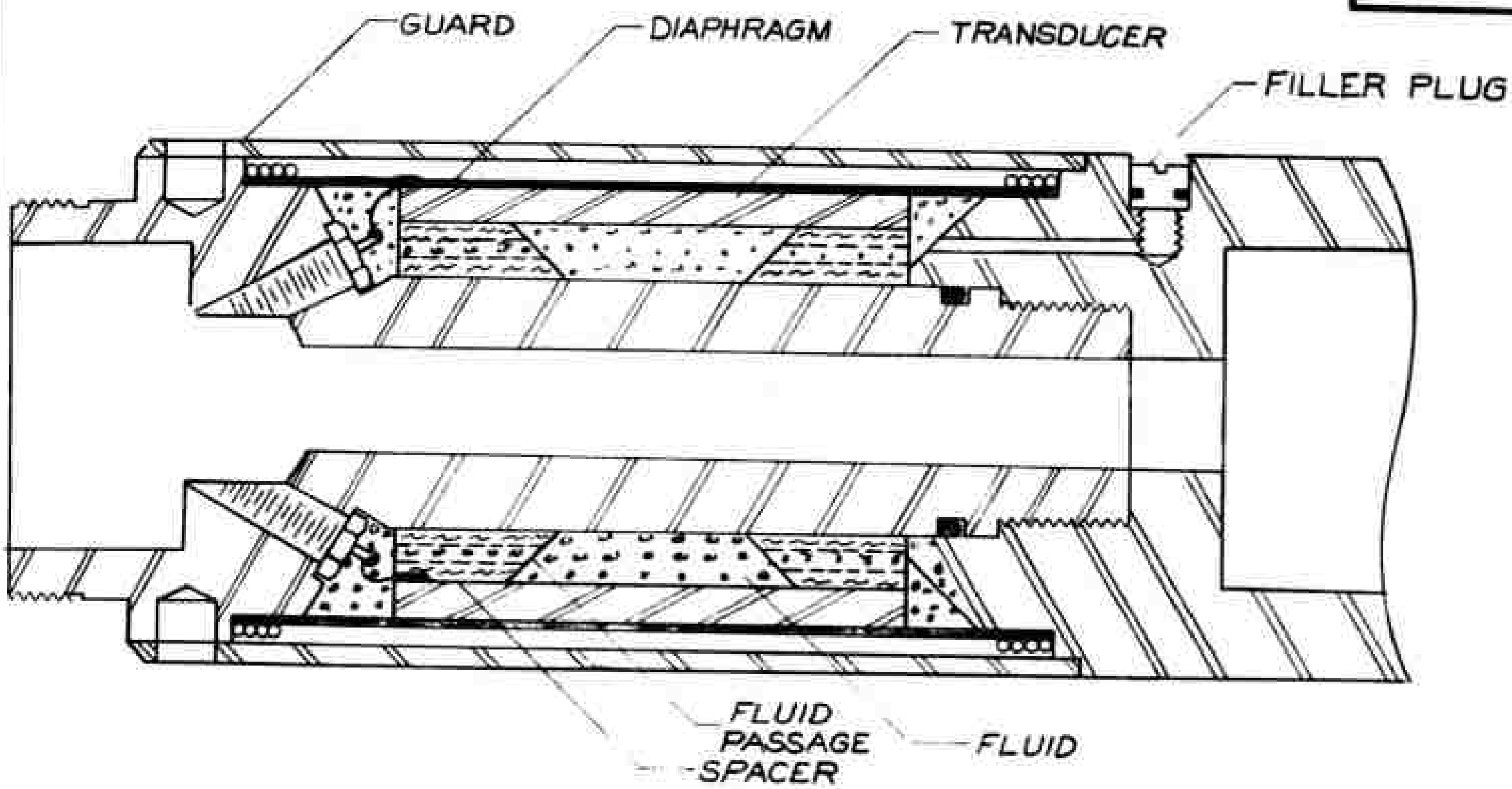
2

FIGURE 1



CENTURY MODEL "C" WELL SEISMOMETER

Figure 2



TOLERANCES
UNLESS OTHERWISE SPECIFIED
FRACTIONS: ± 1/64
DECIMALS: ±.005
ANGLES: ±0°-5'

NEXT ASSEMBLY	NO. REQ'D	LET.	DATE	REVISION	SEE E.O. FOR DETAILS	E. O.	APP'D

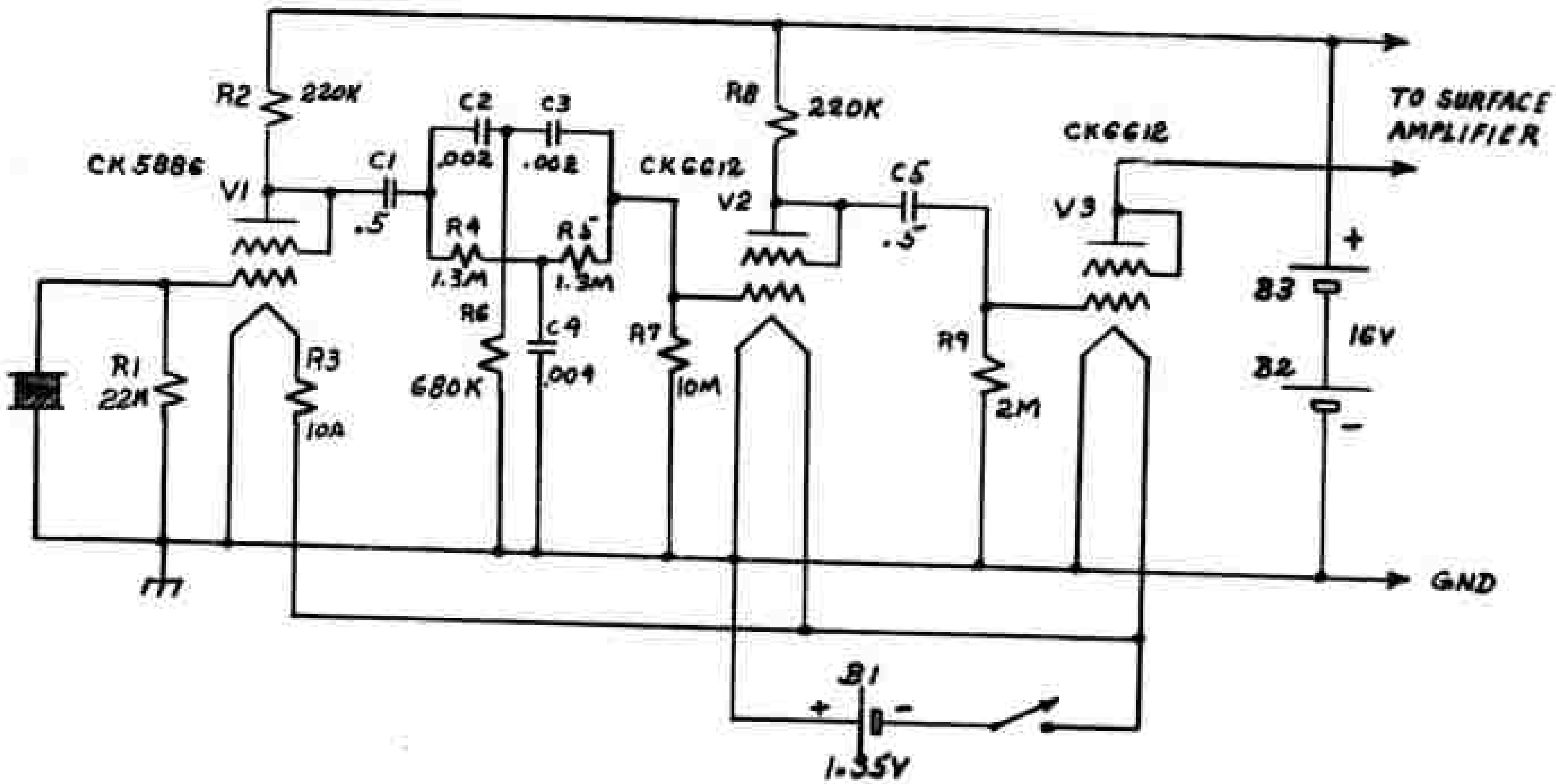
DO NOT SCALE PRINTS

CENTURY GEOPHYSICAL CORP.
TULSA, OKLAHOMA, U.S.A.

TRANSDUCER MOUNTING

DATE 6-14-61

Figure 3



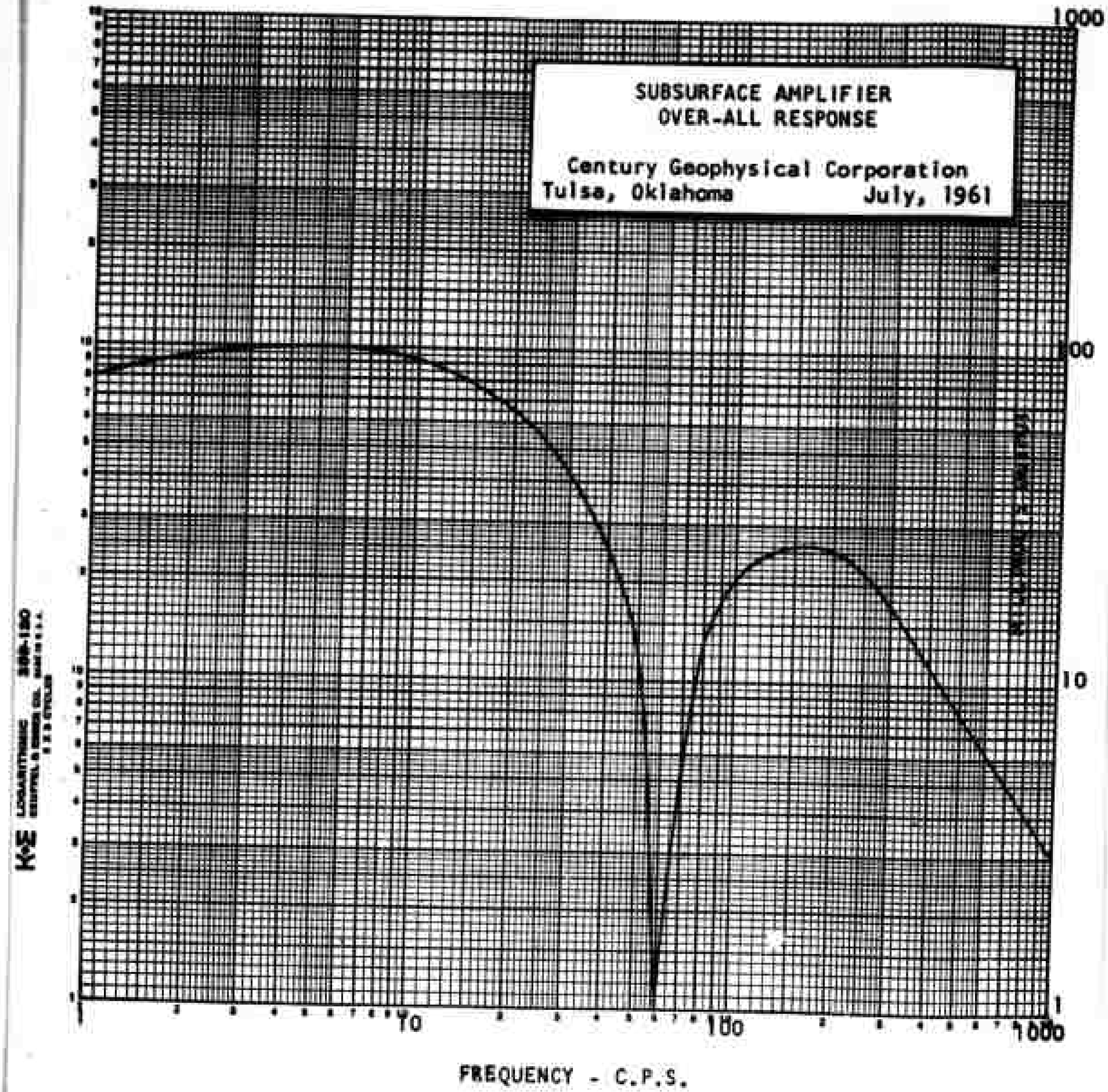
TOLERANCES		NEXT ASSEMBLY	NO. REQ'D	LET.	DATE	REVISION	E. O.	APP'D
FRACTIONS:	± 1/64							
DECIMALS:	±.005							
ANGLES:	±0°-5'							

DO NOT SCALE PRINTS

CENTURY GEOPHYSICAL CORP.
TULSA, OKLAHOMA, U.S.A.

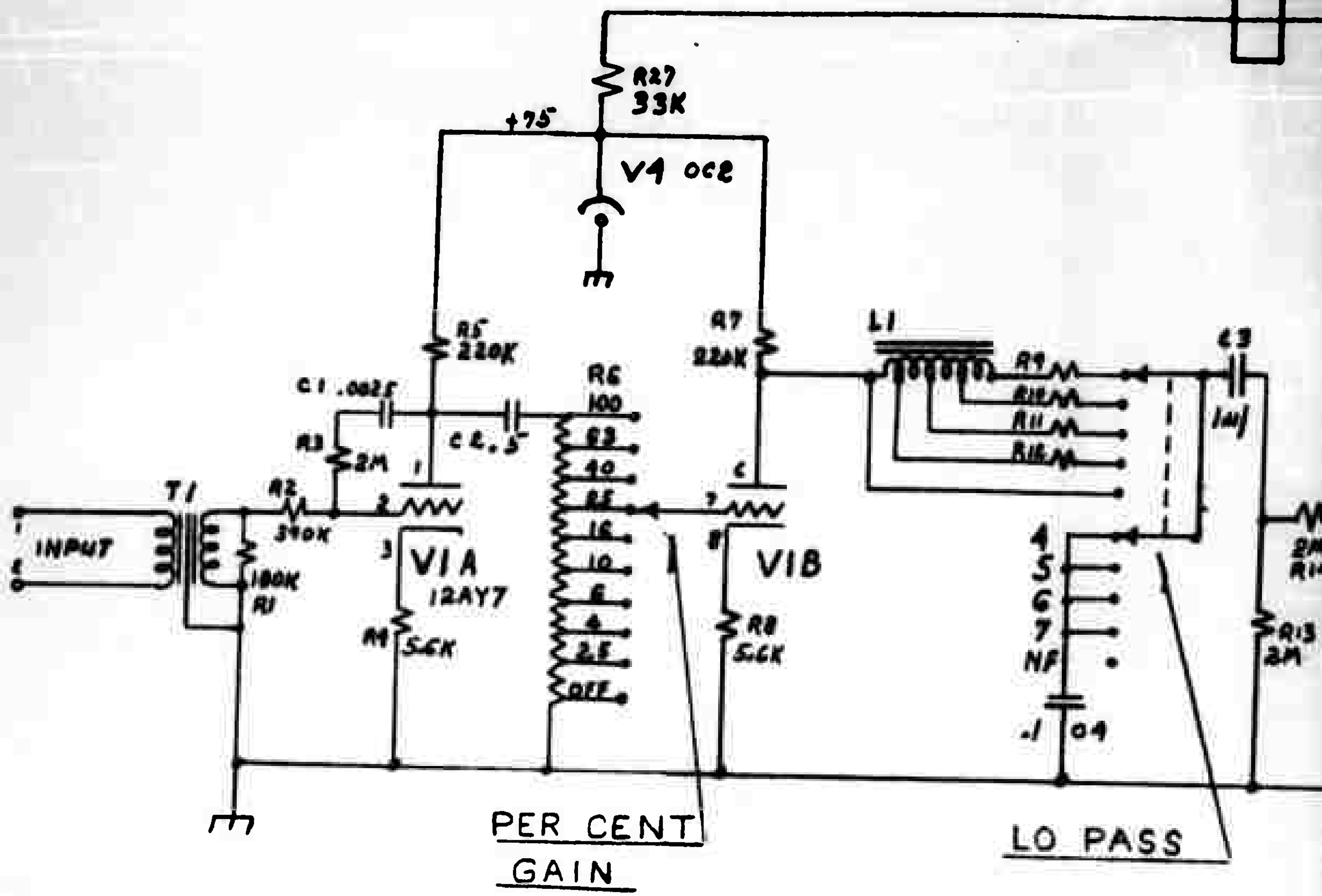
PREAMPLIFIER--
SUBSURFACE

Figure 4



SUBSURFACE AMPLIFIER
OVER-ALL RESPONSE
Century Geophysical Corporation
Tulsa, Oklahoma July, 1961
1000
100
10
1
10
100
1000
FREQUENCY - C.P.S.

Figure 5

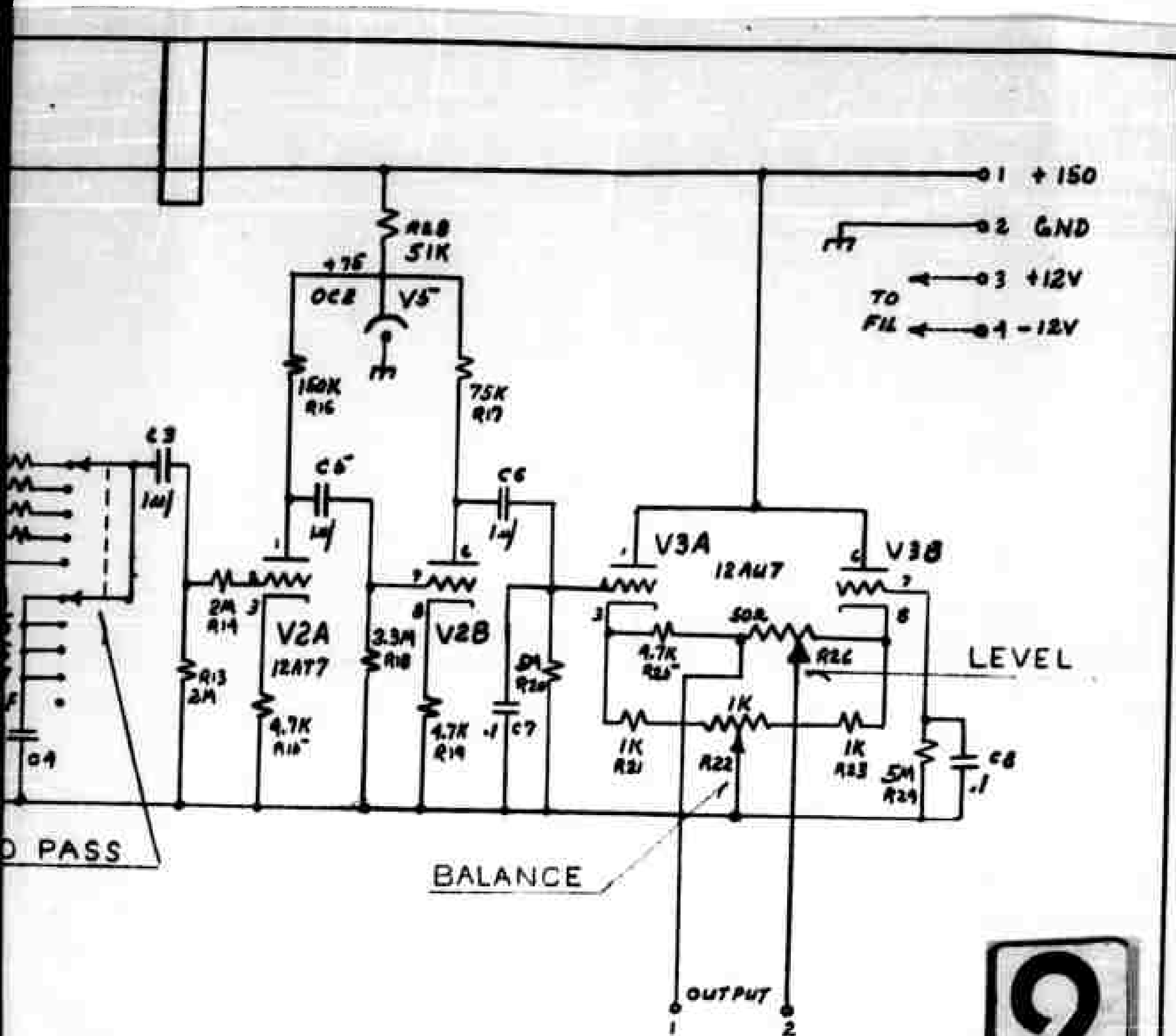


1

MATERIAL

MACHINE FINISH

SURFACE FINISH



2

LET.	DATE	REVISION (SEE E.O. FOR DETAILS)	E.O.	APP'D.

NEXT ASSEMBLY | NO. REQ'D

TOOL NUMBERS

STOCK NUMBER

DO NOT SCALE PRINTS

TOLERANCES UNLESS OTHERWISE SPECIFIED

FRACTIONS: ± 1/64

DECIMALS: ± .005

Century GEOPHYSICAL CORP. TULSA, OKLAHOMA U.S.A.

SURFACE AMPLIFIER

DRAFTSMAN | CHECKED | APPROVED

DATE | SCALE

Figure 6

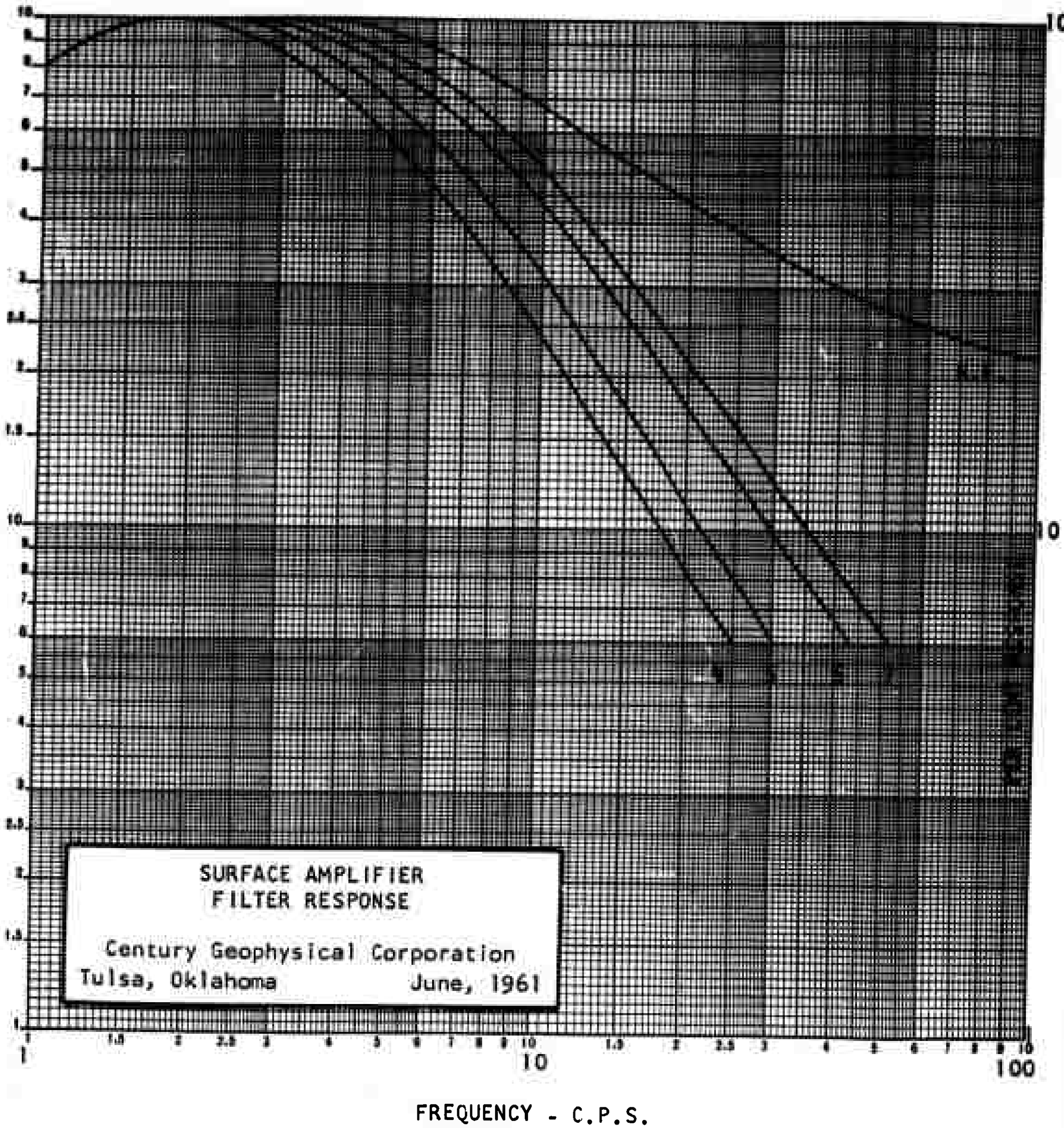
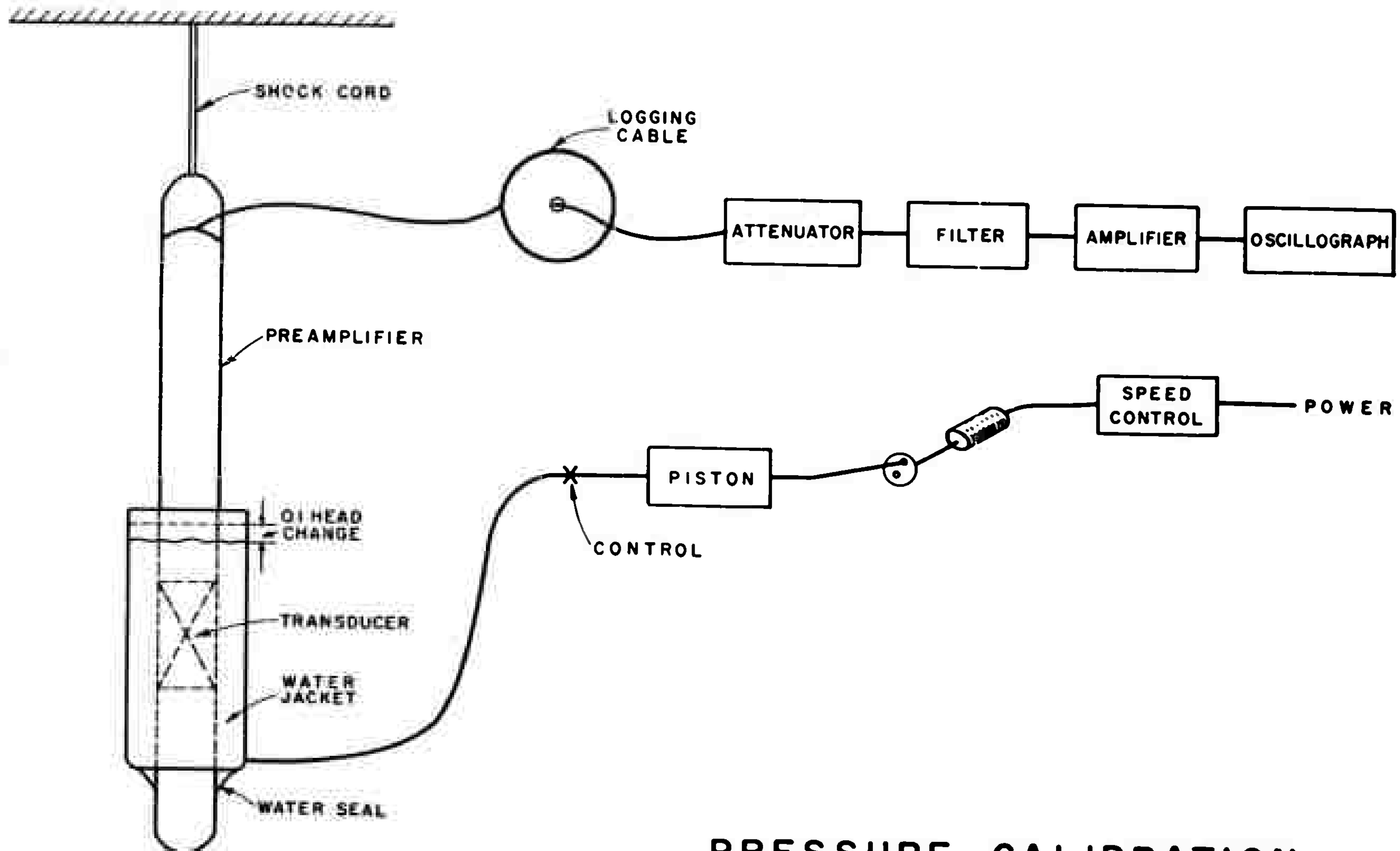

SURFACE AMPLIFIER
FILTER RESPONSE
Century Geophysical Corporation
Tulsa, Oklahoma
June, 1961
FREQUENCY - C.P.S.
1
10
100
100
10

Figure 7



PRESSURE CALIBRATION

FIGURE 8

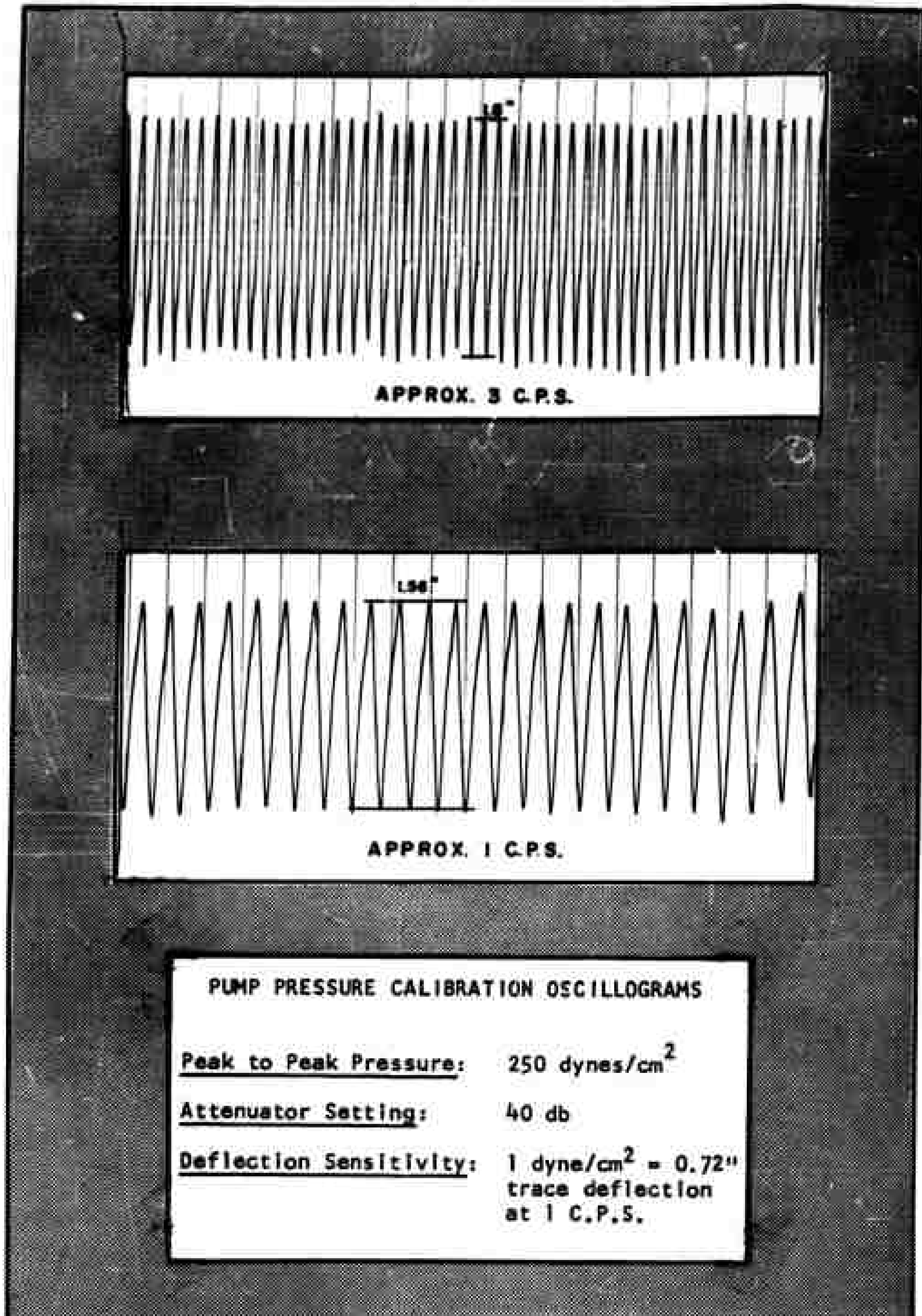

APPROX. 3 C.P.S.
APPROX. 1 C.P.S.
PUMP PRESSURE CALIBRATION OSCILLOGRAMS
Peak to Peak Pressure: 250 dynes/cm²
Attenuator Setting: 40 db
Deflection Sensitivity: 1 dyne/cm² = 0.72" trace deflection at 1 C.P.S.

Figure 9

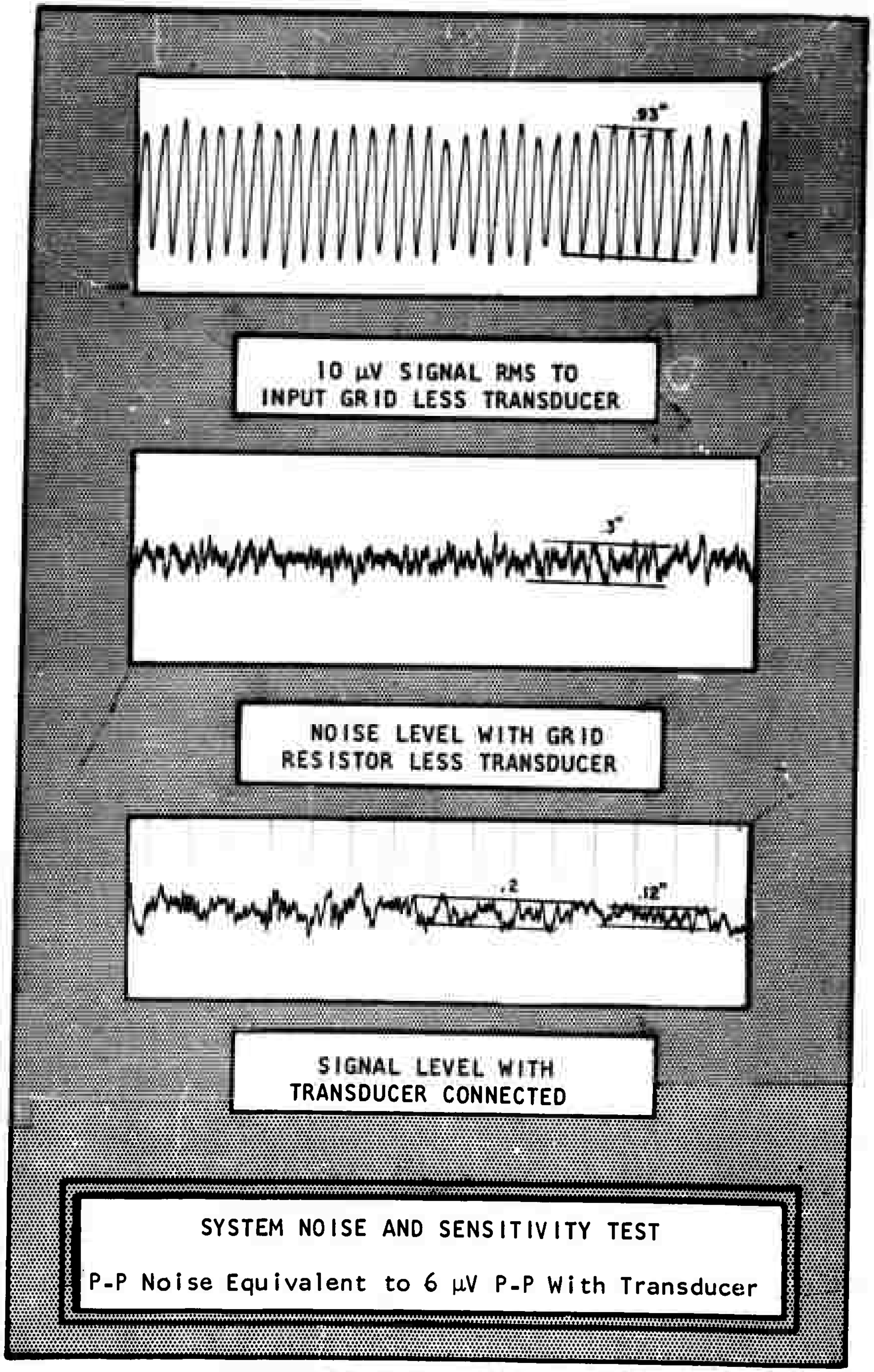

.93"
10 µV SIGNAL RMS TO
INPUT GRID LESS TRANSDUCER
.3"
NOISE LEVEL WITH GRID
RESISTOR LESS TRANSDUCER
.2
.12"
SIGNAL LEVEL WITH
TRANSDUCER CONNECTED
SYSTEM NOISE AND SENSITIVITY TEST
P-P Noise Equivalent to 6 µV P-P With Transducer

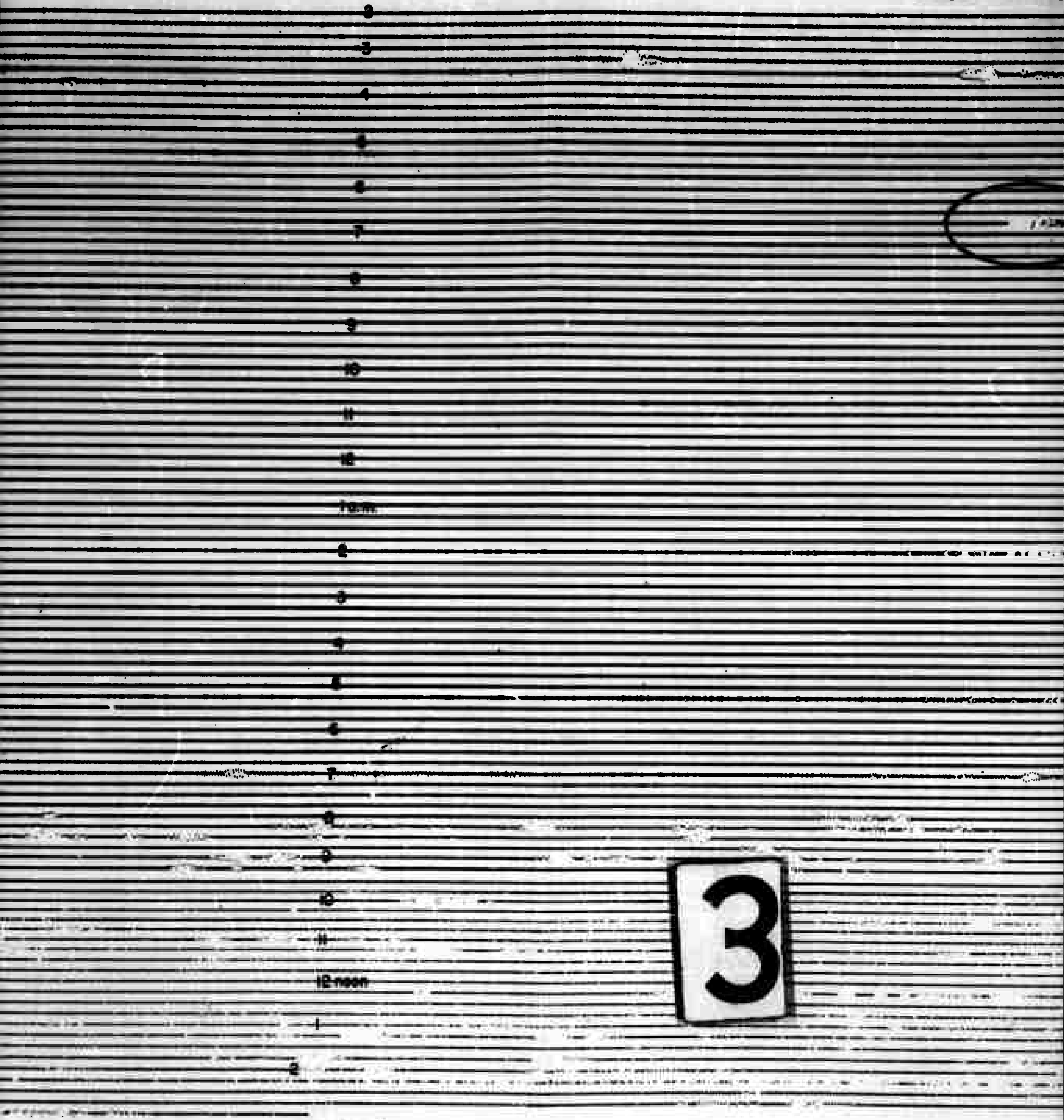
Figure 10

1

2

SHORT PERIOD VERTICAL BENIOFF
5-31-61 TO 6-1-61

MAGNIFICATIO



3pm. 6-1-61

MAGNIFICATION : 12,000

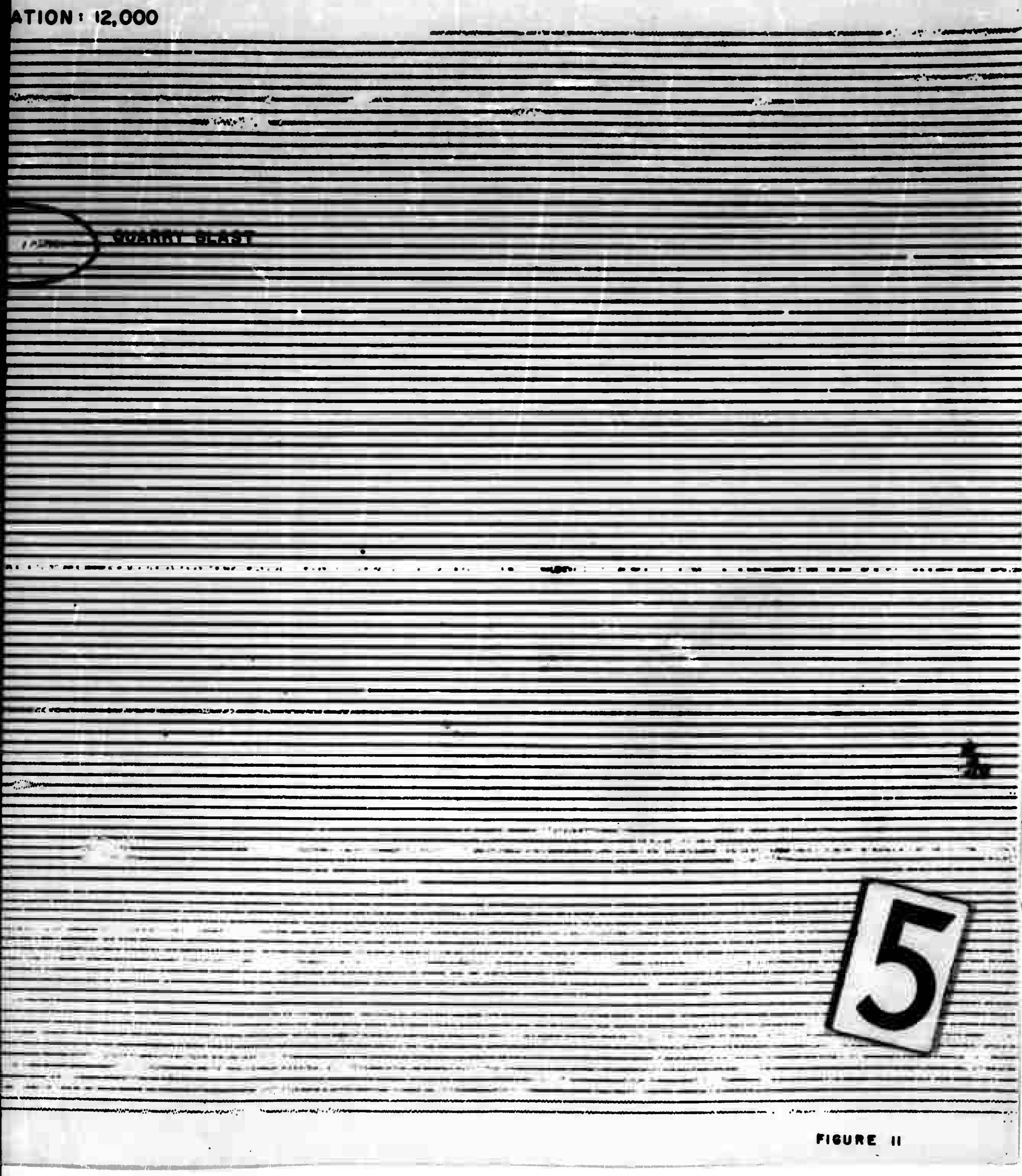
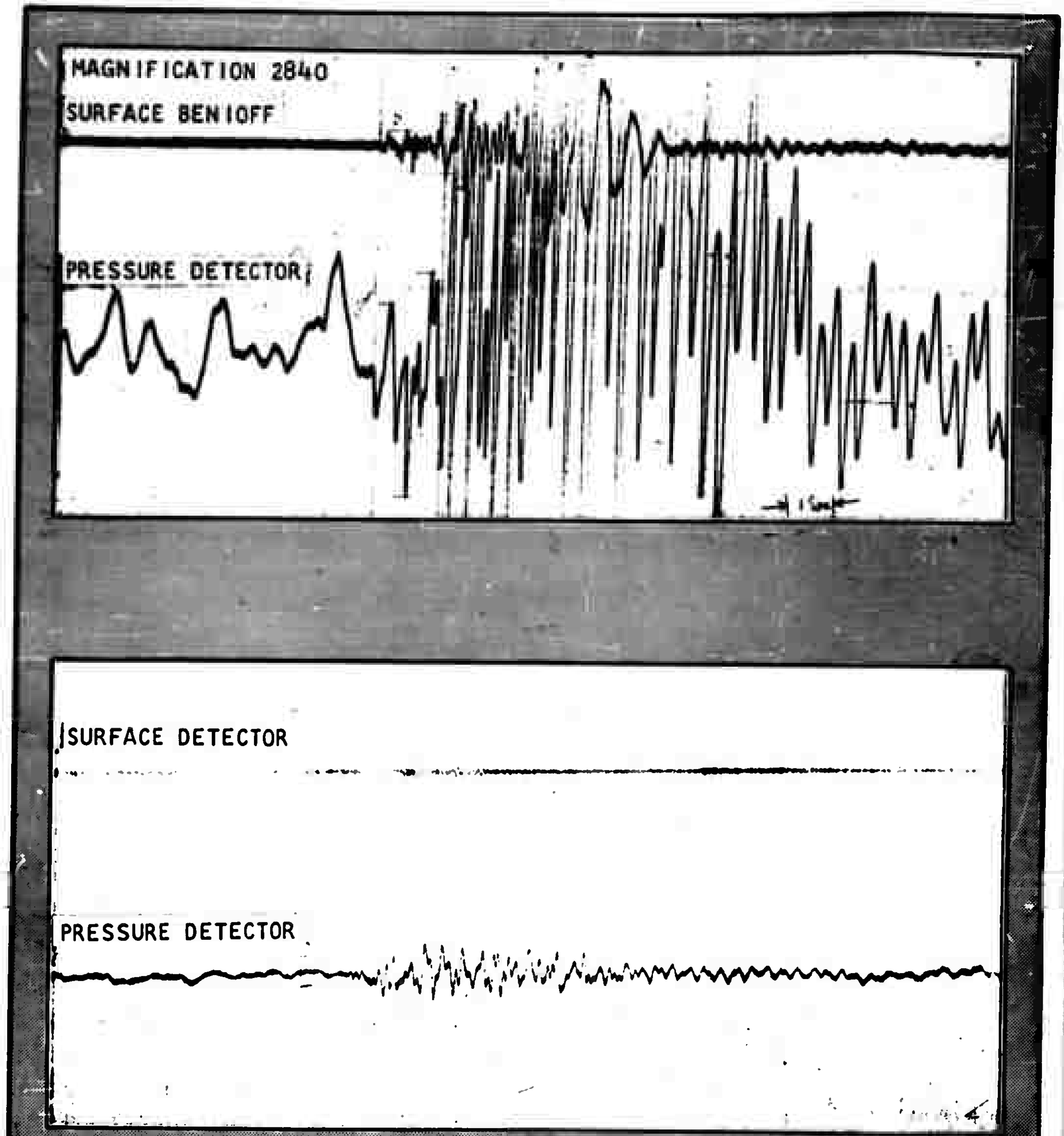
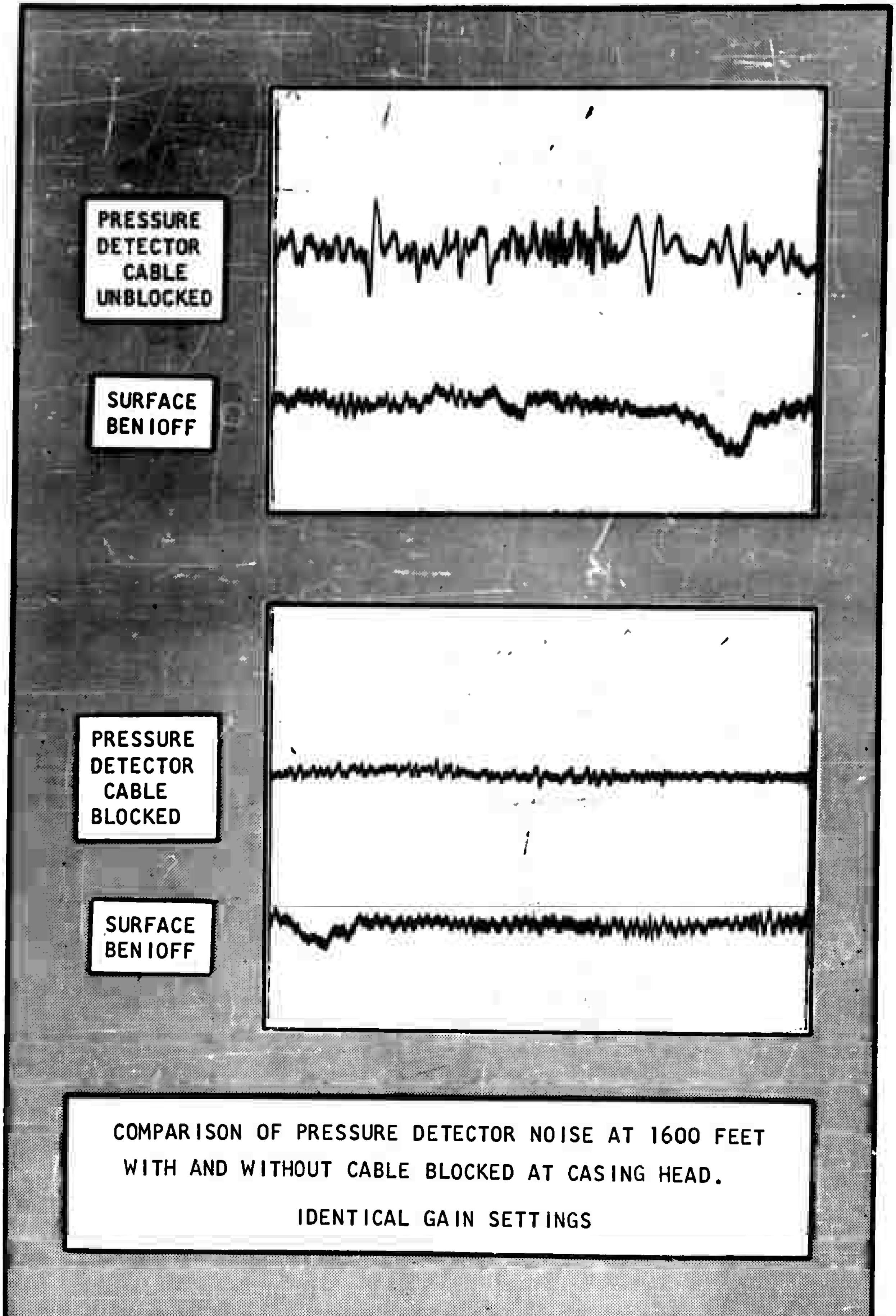


FIGURE 11



QUARRY BLASTING RECORDINGS AT 1300 FEET DEEP

Figure 12



COMPARISON OF PRESSURE DETECTOR NOISE AT 1600 FEET WITH AND WITHOUT CABLE BLOCKED AT CASING HEAD.

IDENTICAL GAIN SETTINGS

Figure 13

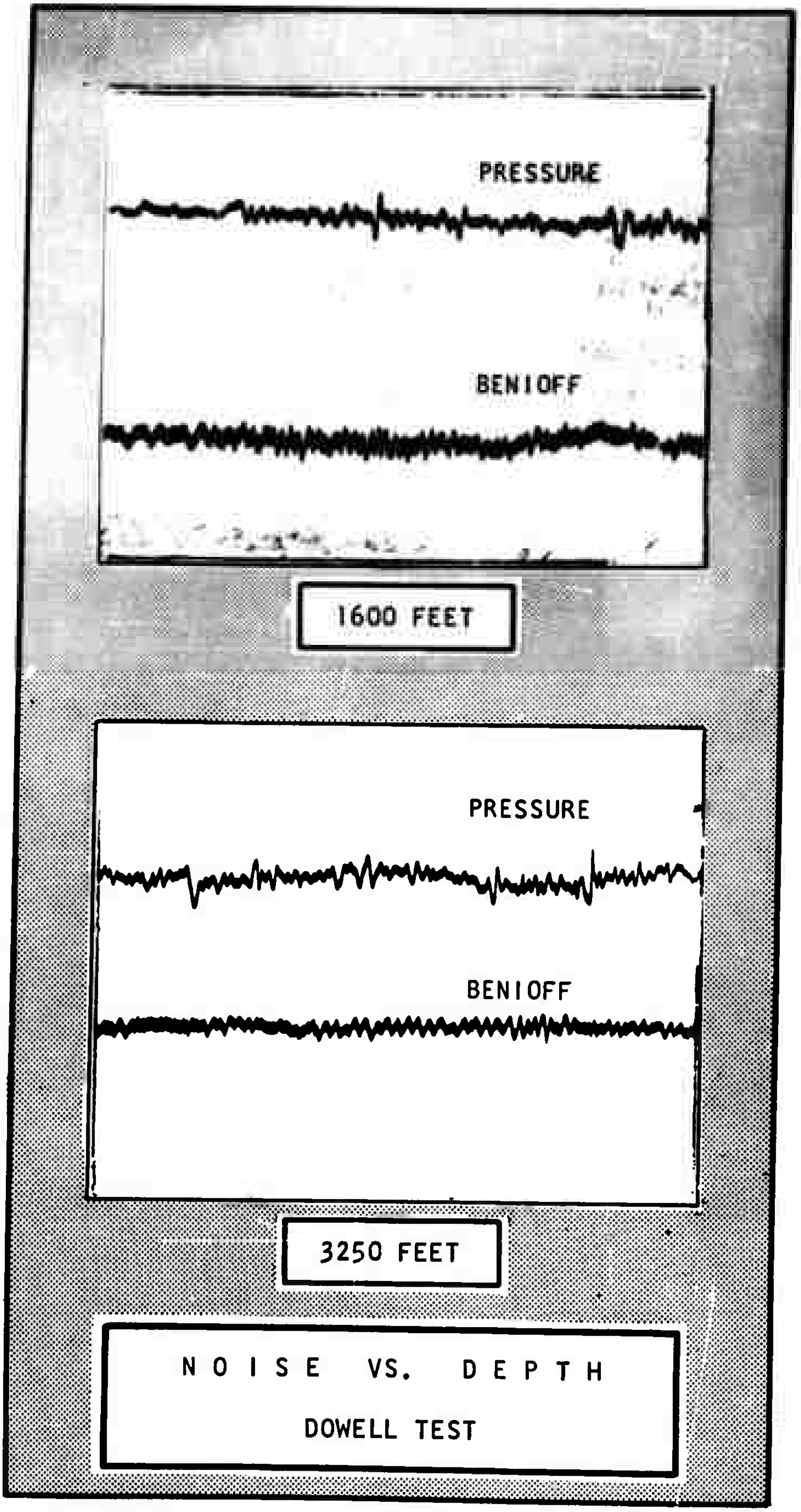
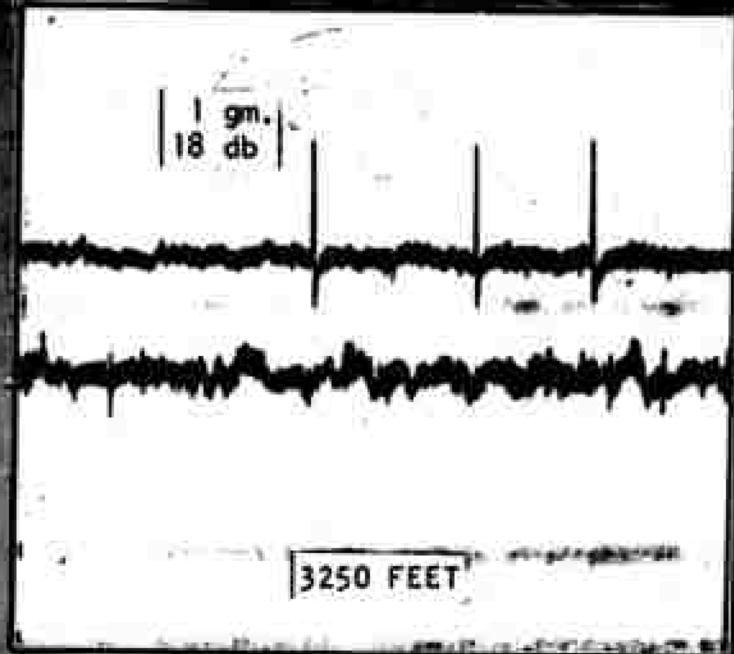

PRESSURE
BENIOFF
1600 FEET
PRESSURE
BENIOFF
3250 FEET
N O I S E VS. D E P T H
DOWELL TEST

Figure 14



$$M = 95 \left(\frac{X_1}{W_t}\right)$$

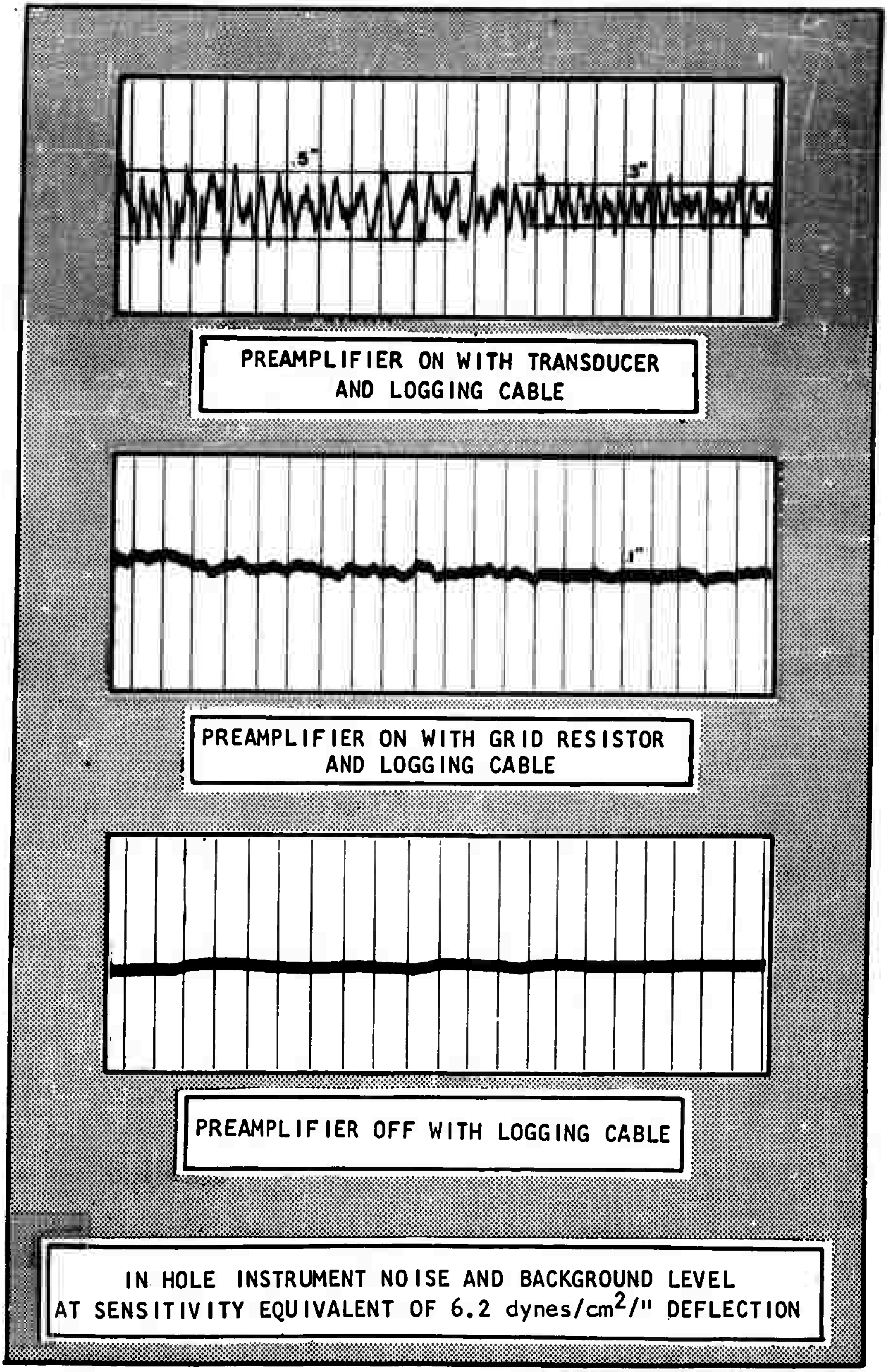
X_1 = 15 mm at 18 db
W_t = 1 gram

M = 1,410 at 18 db

M = 12,690 at 0 db

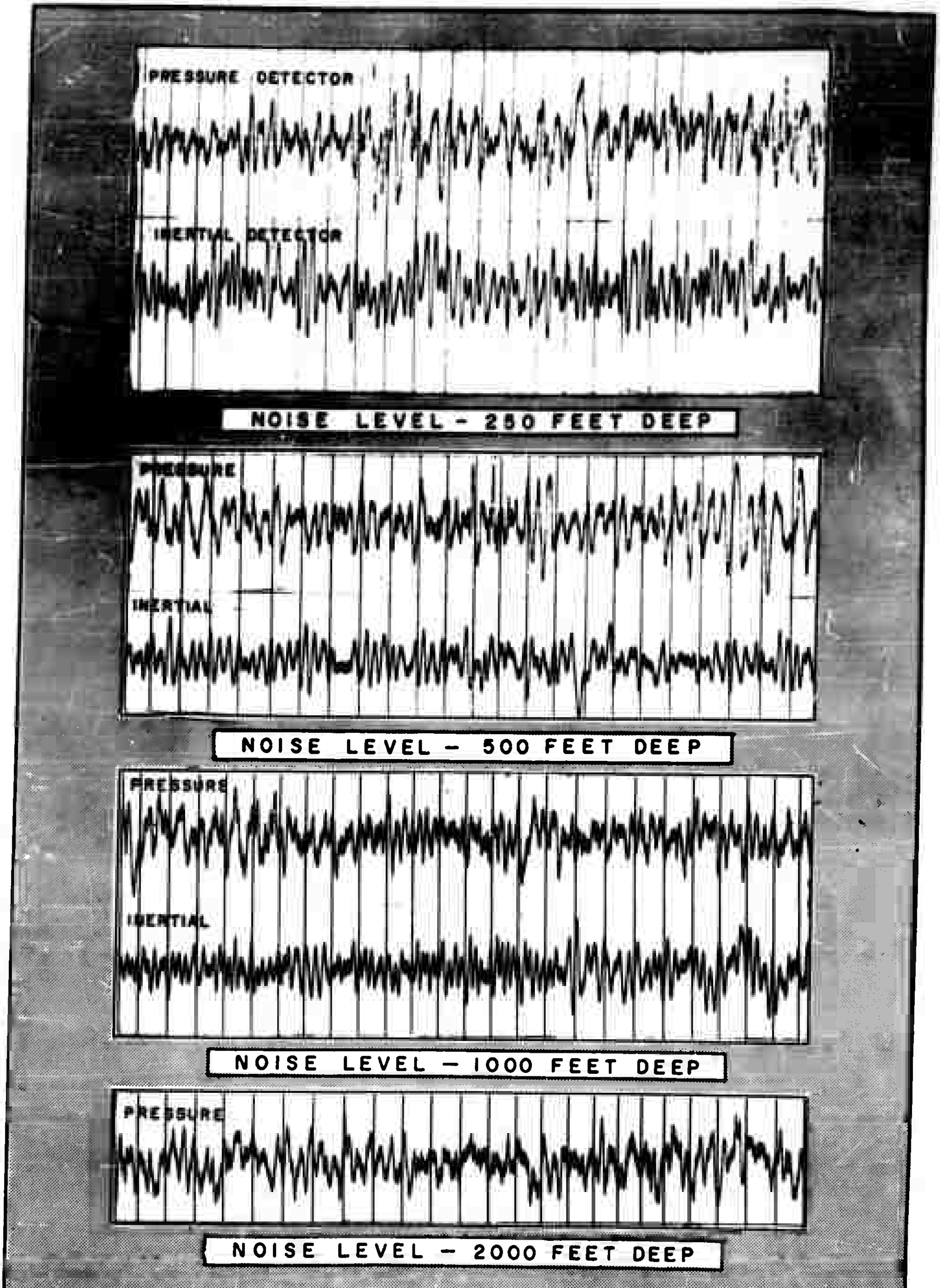
BENIOFF CALIBRATION AT DOWELL TEST

Figure 15



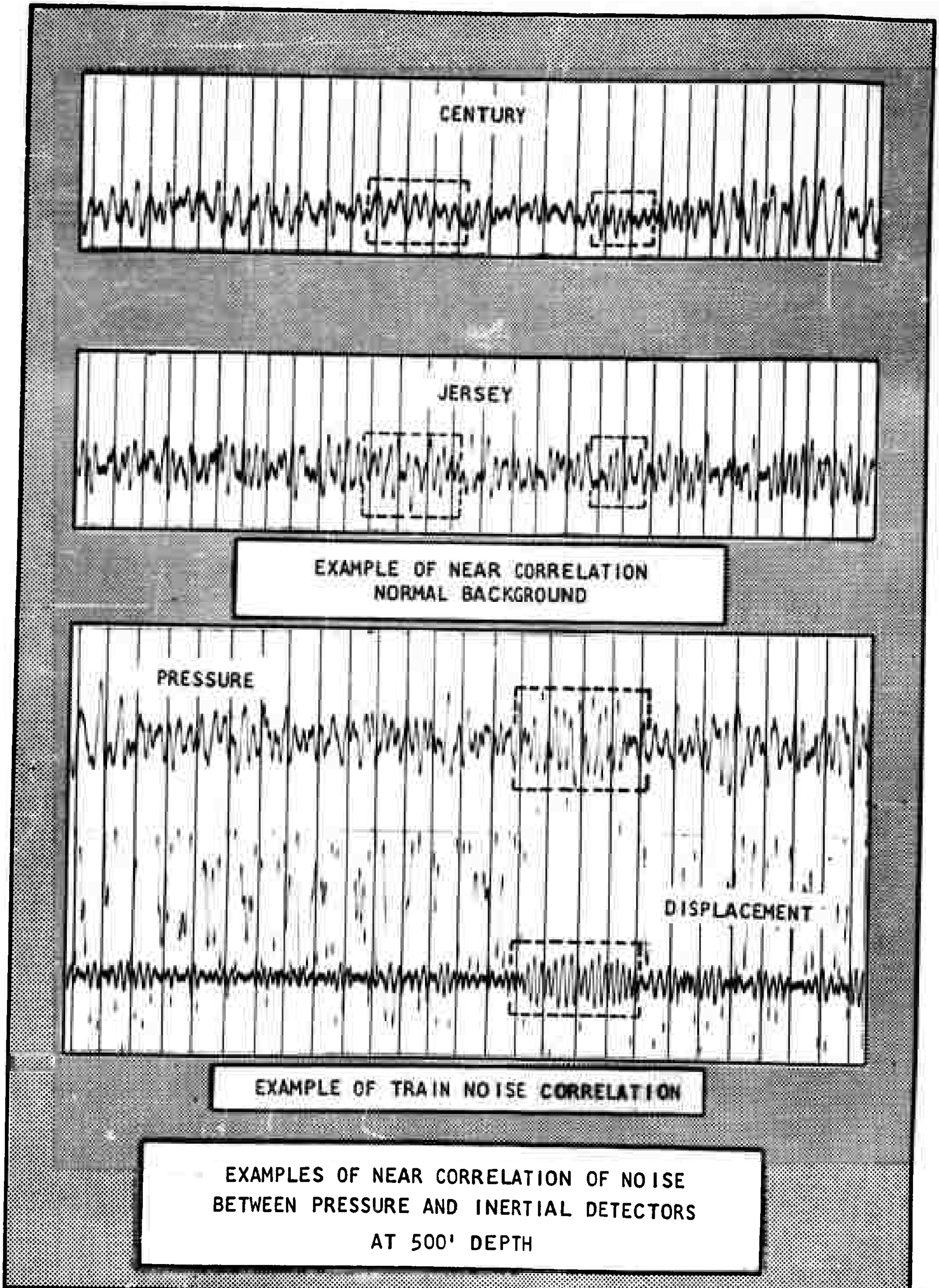
IN HOLE INSTRUMENT NOISE AND BACKGROUND LEVEL AT SENSITIVITY EQUIVALENT OF 6.2 dynes/cm^2/" DEFLECTION

Figure 16



BACKGROUND NOISE LEVEL COMPARISON VS. DEPTH

FIGURE 17



EXAMPLES OF NEAR CORRELATION OF NOISE BETWEEN PRESSURE AND INERTIAL DETECTORS AT 500' DEPTH

Figure 18

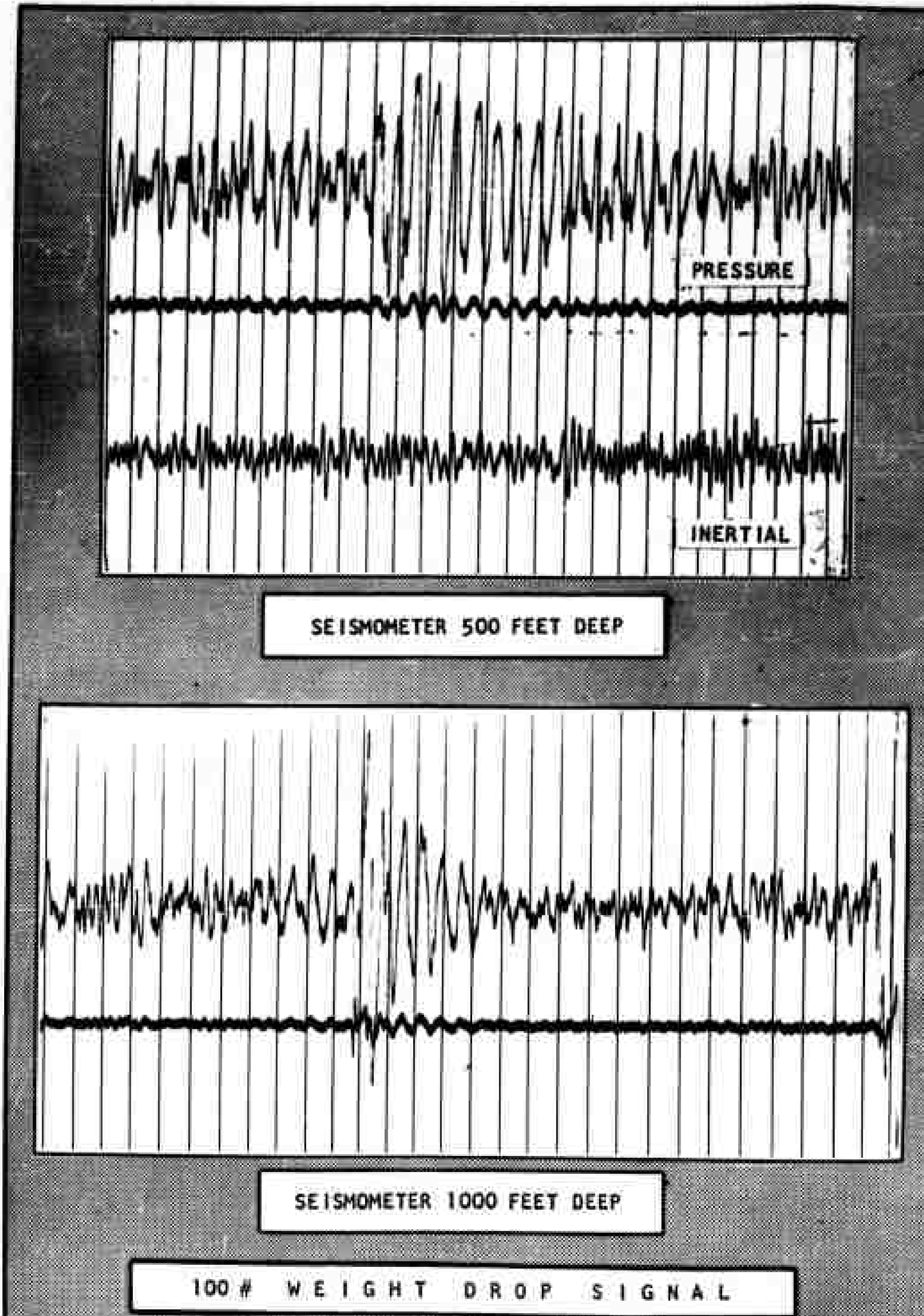
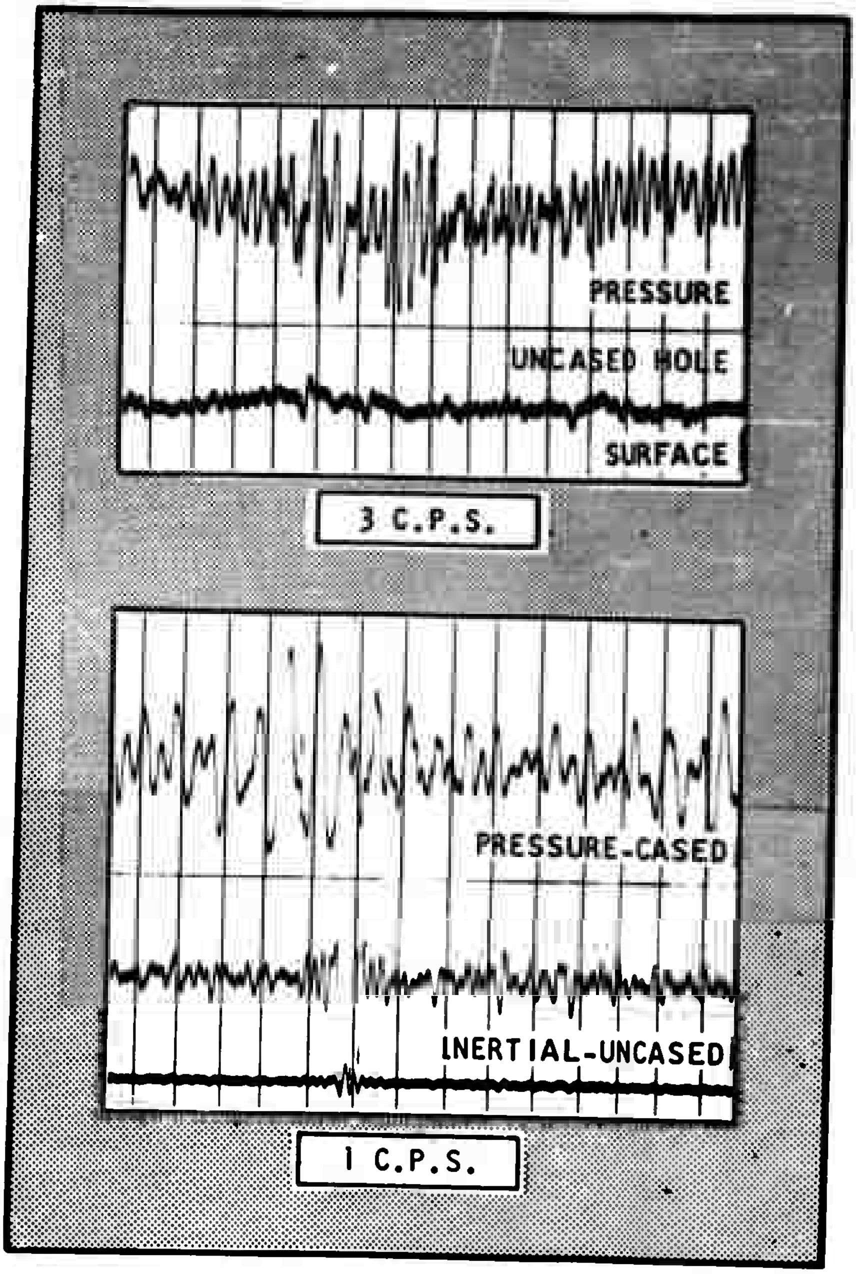

PRESSURE
INERTIAL
SEISMOMETER 500 FEET DEEP
SEISMOMETER 1000 FEET DEEP
100# WEIGHT DROP SIGNAL

Figure 19



CHEMICAL EXPLOSIVES: 10# CHARGE AT 130 FEET DEEP
6000 FEET FROM DETECTORS

DETECTORS 500 FEET DEEP

UNCASED HOLE

Figure 20

UNCLASS

UNCLAS

BEST
AVAILABLE COPY